Using and Implementing Continuous Stirred-Tank Reactors and Plug Flow Reactors to Study Reactions in Undergraduate Chemical Engineering

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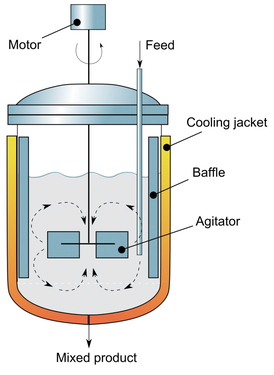
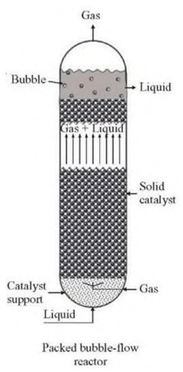
Introduction

Chemical reactions occur in reactors, either through a batch reactor or continuous-flow reactors. The rate of a reaction is studied using chemical kinetics. The combination of chemical kinetics and reactor design is primarily studied by Chemical Engineers. In this work, two flow reactors are analyzed: Continuous Stirred Tank Reactors (CSTR) and Plug Flow Reactors (PFR), which are heavily used by chemical industries. Preliminary data of a saponification reaction was collected using CSTR and PFR. The proper functioning of the equipment and the data collection interface are evaluated before using this equipment in the Chemical Engineering Unit Operations Laboratory. Additional experiments are proposed.



CSTR



PFR

Objectives

- Assemble a CSTR Equipment and a PFR Equipment (Armfield Ltd)
- Propose and Test Qualitative Experiments
- Propose and Test Quantitative Experiments
- Propose Capstone Experiments for Future Study

Methodology

- CSTR and PFR behavior were studied at the same volumetric flow rates
- Solutions of 0.1 M were used for all reagents

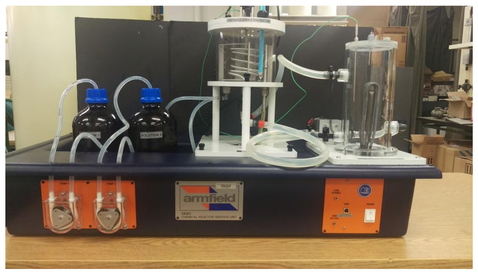
Baseline Reaction

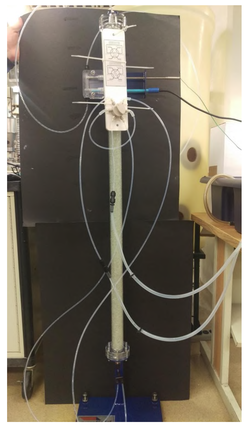
Saponification of Ethyl Acetate with Sodium Hydroxide

$CH_3CO_2C_2H_5 + NaOH \rightarrow C_2H_5CO_2Na + CH_3OH$

Equipment Used

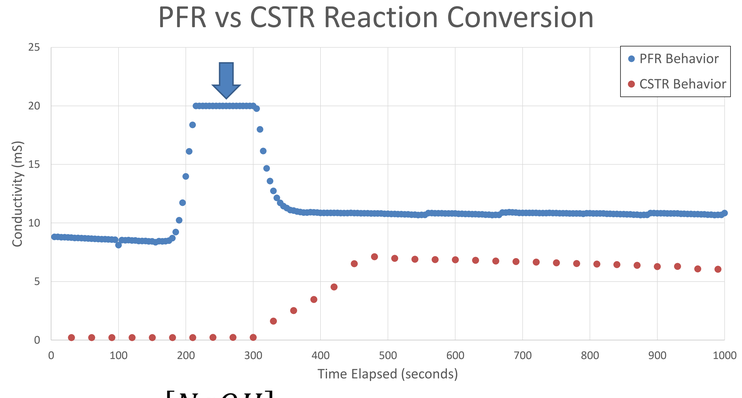
- Armfield CEM-MKII (CSTR)
- Armfield CEY (PFR)
- Armfield CEXC (Control Base)
- Conductivity Sensor





Results & Discussion

- Saponification Reaction
  - Expected to exhibit irreversible second order kinetics
- Conversion determined via conductivity
  - Hydroxide Ion are major contributors
  - All other species contribute very little
- Overall Conversion of Saponification
  - Higher in CSTR compared to PFR at similar flow rates
  - This difference can be explained by
  - Fluid resonance time in reactors
  - Start-up procedures and effects on steady state behavior



$$-d\frac{[NaOH]}{dt} = k[NaOH][CH_3CO_2C_2H_5]$$

Future Work

Applications extend into future student education and experimental work:

- Study results provide baseline data for instructors, which can be used to guide students
- Opens avenues for student capstone experiments, including the one outlines below

An ***additional reaction*** to study is the reaction between hydrogen peroxide and bleach:

$$H_2O_2 + NaOCl \rightarrow H_2O + NaCl + O_2$$

This reaction would be suitable for study due to the rapid kinetics and exothermic properties:

- Studies controlling or limiting reaction conversion as oppose to maximizing conversion are possible
- Studies examining heat transfer dynamics in a CSTR are possible
- Studies that analyze effluent gas production instead of solution conductivity would be possible due to gaseous O_2 production
- Raw materials are not expensive to purchase, and reaction products are not hazardous

Conclusions

Continuous Stirred Tank Reactor and Plug Flow Reactor installation and modelling was successful, and the saponification reaction used in this process has been deemed appropriate for undergraduate study. Additional reactions for ChE senior students are proposed, and should be considered as part of final research projects.

Acknowledgements

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References

[1] Levenspiel, Octave. *Chemical Reaction Engineering*. J. Wiley & Sons, 1999.